

# **Hurricane Wave Topography and Directional Wave Spectra in Near Real-Time**

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## **LONG-TERM GOALS**

Develop a simple parameterization for the directional wave spectrum in the vicinity of a hurricane.

## **OBJECTIVES**

Develop and/or modify the real-time operating system and analysis techniques and programs of the NASA Scanning Radar Altimeter (SRA) to process the SRA wave topography data into directional wave spectra during hurricane flights. Upload the spectra and the topography onto a web site immediately post-flight to make them available to ONR investigators.

## **APPROACH**

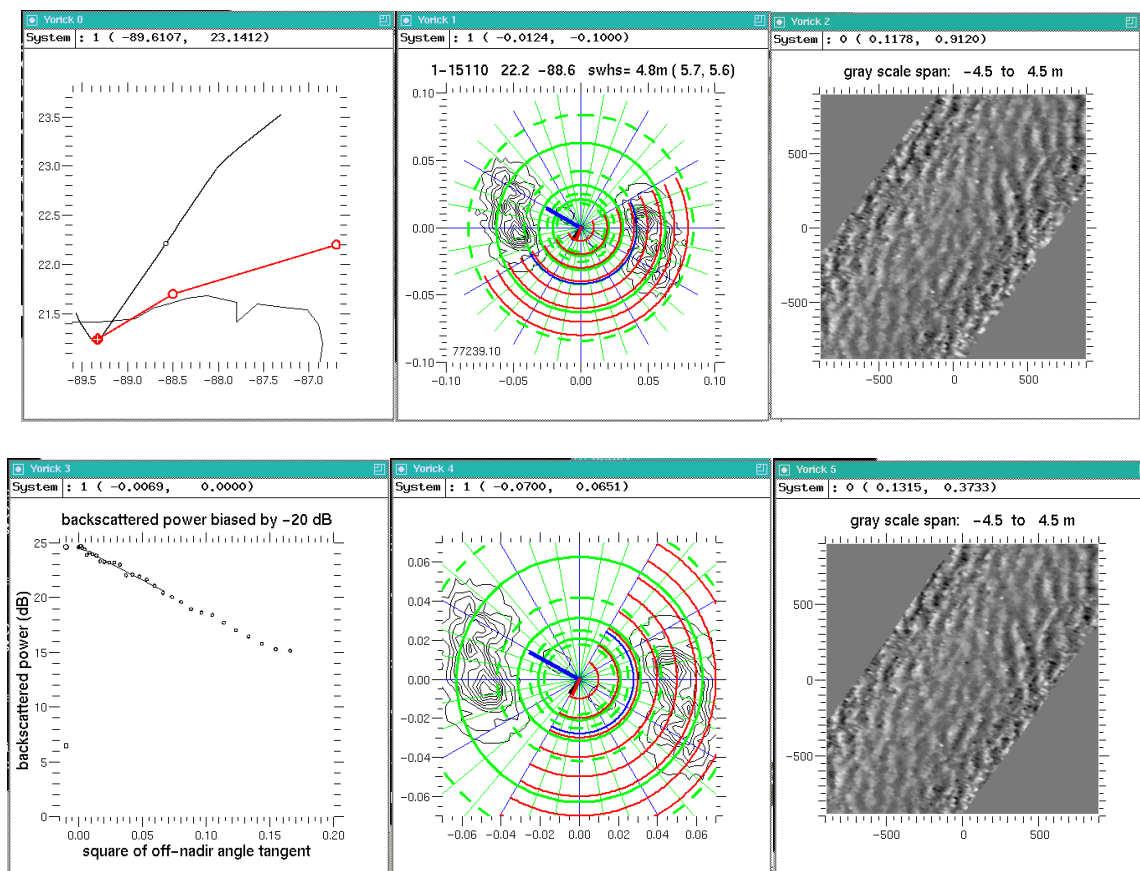
The SRA has a long heritage in measuring the energetic portion of the sea surface directional wave spectrum (Walsh et al. 1985; 1989; 1996, 2002; Wright et al. 1999; 2001). There is an ambiguity of 180° in the direction of propagation of waves determined from topographic data. To obtain the directional wave spectrum, the energy of the FFT encounter spectrum must be doubled everywhere, the artifact lobes deleted, and the real lobes Doppler-corrected. Identifying the artifact lobes for deletion and partitioning the real spectral lobes into the various wave components has been a slow and labor-intensive process. Edward J. Walsh has overall responsibility for developing the techniques and corrections to enable this analysis to be performed during the aircraft flights. C. Wayne Wright will be responsible for the real-time operating system of the SRA and making whatever modifications may be required to enable near real-time processing of the data. He will also be responsible for developing and maintaining the web site for post-flight ONR access to the data.

## **WORK COMPLETED**

A sequence of four programs has been developed to process SRA data into spectra on the aircraft. **onac0getall.ex**, written in TCL/Expect, captures the aircraft, GPS, and SRA data from the SRA and

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GPS computers and consolidates it in a processing file on a Linux laptop computer which is connected to the SRA for processing during the flights and then carried off the aircraft for data transfer and additional ground processing and program development. The other three programs are written Yorick. **onac1xyz.i** processes the raw SRA range measurements into an x, y, z grid of wave topography. **onac2fft.i** takes the output of onac1xyz.i and produces directional wave spectra. **onac3rev.i** deletes the artifact lobes and displays the output spectra of onac2fft.i as an animation playback at up to 200 times the acquisition speed to assess the spectral evolution. Figure 1 shows a sample screen from onac2fft.i during the flight aboard NOAA WP-3D aircraft N43RF into Hurricane Isidore on 9/22/2002.



**Figure 1. Displays presented by onac2fft.i during Hurricane Isidore flight on 22 September 2002. [images of hurricane and aircraft tracks, directional wave spectra, and SRA wave topography]**

The top left panel shows the hurricane track in red (generated by eye fixes shown by circles, with most recent filled, input to file eyefix.txt prior to running onac2fft.i), the Yucatan Peninsula in the vicinity of 21.5N, and the aircraft track for the SRA file being processed with the center of the being transformed indicated by the small circle at about 22.2N, 88.6W. The top right panel shows the full swath (64 points) of SRA wave topography data at that location which fits within the 1.8 km square window used in generating wave spectra (about 200 scan lines). The data near the edges of the swath are more noisy than in the middle because of the higher incidence angle and reduced signal level because of antenna pattern and backscatter fall-off, and, at times, rain. onac2fft.i allows a different

edge cropping for each wave spectrum and the cropped topography is shown in the bottom right panel (only 2 points along each edge in this instance).

The top middle panel shows the directional wave spectrum resulting from the 2-dimensional FFT applied to the cropped topography data in the lower right panel. Both real and artifact lobes are shown and the red semicircles are the recommendation of a model developed during the past year for which half-plane contains the artifact lobes to be deleted. The blue radial extends in the downwind direction an amount proportional to the wind speed at the aircraft flight level (1.5 km in this instance). The aircraft heading and ground track are indicated by the short red and black radials, respectively. Since the model is approximate and does not include the effect of land, its recommendation can be modified and the result is displayed enlarged in the lower middle panel of Figure 1. The bottom left panel shows the data segment backscattered power falloff with incidence angle and a fitted straight line that can be used to determine sea surface mean square slope (mss, small-scale surface roughness) and rain rate.

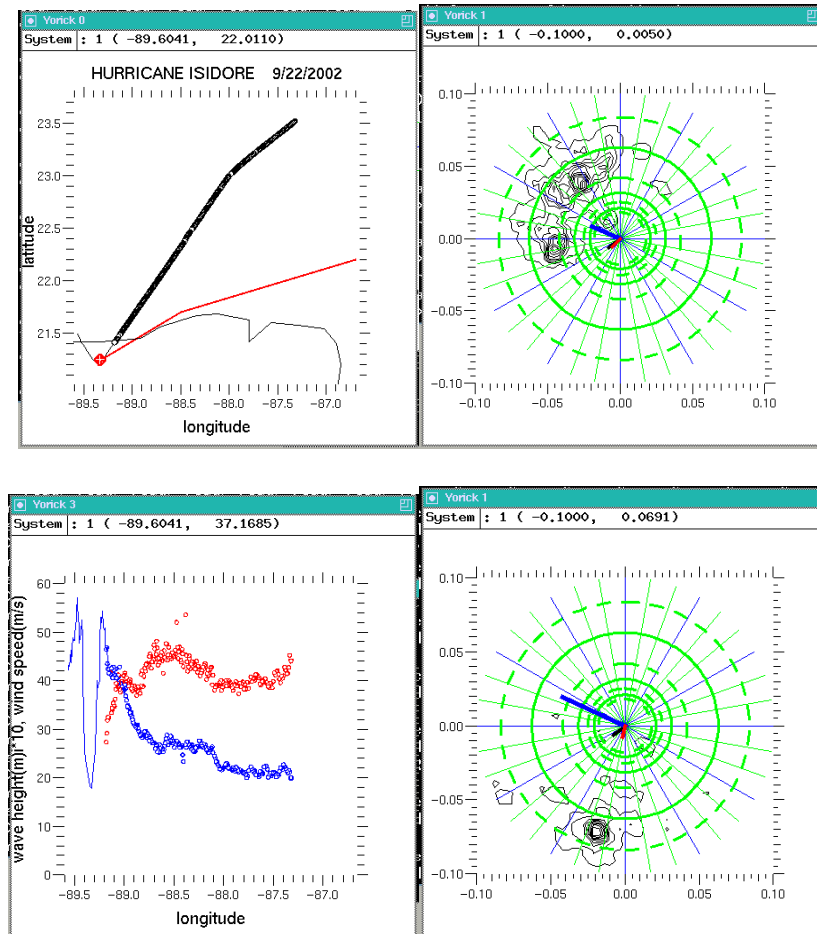
The program retains the tweaks on swath width and half-plane orientations from the previous case, but waits for operator inputs for each succeeding case to either accept or modify the prior values before proceeding. Once the operator has optimized the result, he inputs a quality assessment for the final spectrum and power falloff to serve as editing criteria in `onac3rev.i`. In a time trial during the Hurricane Isidore flight for the 50-minute flight line shown in Figure 1, it took the operator over three hours to process the data while monitoring the continual collection of data with the SRA. Methods to increase speed are under investigation. The left and right swath cropping values determined subjectively by the operator will be compared with the signal level associated with each range measurement to develop a hands-off algorithm to incorporate in `onac2fft.i`.

## RESULTS

There are presently three panels displayed by `onac3rev.i` to provide a rapid review of the output of `onac2fft.i`. In Figure 2, a fourth panel has been added so that the initial and final spectra could be displayed. A series of small circles in the top left panel shows the progression of the observation point along the aircraft track. The top right panel displays the directional wave spectrum at that location with the artifact lobes deleted. In Figure 2, it is the initial spectrum of the flight line. The bottom right panel is not part of the normal `onac3rev.i` display, but has been added to show the spectrum closest to the beach not corrupted by land on the inbound run. The bottom left panel is registered in longitude to the plan view of the panel above and plots in blue circles the wind speed at the aircraft flight level (1500 m in this instance) and the significant wave height (red circles) determined by integrating the SRA directional wave spectrum.

In the initial spectrum (23.5N, 87.3W) there are two wave components of about 140 m wavelength, propagating towards the west and northwest, with the downwind direction approximately between them. The bottom left panel of Figure 2 indicates the wind speed at this location, well away from the eye, was only 20 m/s. The waves generally had propagation directions near the downwind direction for the first half of the inbound flight line. The bottom left panel shows the wave height increasing with wind speed in the region. But as the wind begins a rapid increase at about 88.6W, the wave height decreases due to fetch-limiting by the Yucatan Peninsula.

At about the point at which the wave height begins to decrease, the wave field propagation direction begins to rotate toward the south. The bottom right panel of Figure 2 shows that the waves closest to the shore are propagating at orthogonal to the 46 m/s wind (at aircraft flight level) and the wavelength has shortened to about 80 m due to bathymetric effects.



**Figure 2.** Displays presented by *onac3rev.i* for Hurricane Isidore flight on 22 September 2002. [hurricane and aircraft tracks, directional wave spectra, graphs of wind speed and wave height]

## IMPACT/APPLICATIONS

The SRA is providing the first quantified measurements of the directional wave spectrum spatial variation in the vicinity of hurricanes. The data will impact all the assessments of air/sea interaction in the hurricane environment and serve as a basis for validating wave models under those extreme conditions. The ability to be able to examine the three dimensional structure of individual waves and wave groups will also be very important for assessing the viability of various marine structures.

## TRANSITIONS

The SRA directional wave spectra will be used by other investigators to provide a basis for the interpretation of the wave effects on the air/sea quantities of interest to ONR.

## RELATED PROJECTS

All hurricane components of ONR CBLAST.

## SUMMARY

The NASA Scanning Radar Altimeter produces a topographic map of the sea surface, enabling study of the characteristics of individual waves, groups of waves, and the directional wave spectrum. Since the wave field is the air/sea interface, knowledge of it is important in the study of air/sea transfer processes.

Because it requires both time and distance for waves to grow, their properties tend to represent averages over the wind field temporal and spatial variations. The spatial variation of the direction of propagation of the various components of the complex directional wave spectrum of hurricanes show enough similarity that a model has been developed to recommend which lobes of the directional wave spectrum developed from the SRA wave topography are the artifacts. Computer programs have been developed to process the SRA data into wave spectra on the aircraft, but the process is not yet fully automated.

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Walsh, E. J., C. W. Wright, D. Vandemark, W. B. Krabill, A. W. Garcia, S. H. Houston, S. T. Murillo, M. D. Powell, P. G. Black, F. D. Marks, 2002: Hurricane directional wave spectrum spatial variation at landfall, *J. Phys. Oceanogr.*, **32**, 1667-1684.

## **PATENTS**

None.